

**NIST**

**UNITED STATES DEPARTMENT OF COMMERCE**  
**National Institute of Standards and Technology**  
Gaithersburg, Maryland 20899

## **SAFETY AND ENVIRONMENTAL ASPECTS OF NAVY FIREFIGHTER TRAINERS**

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### **1. ABSTRACT**

A new generation of devices to train Navy firefighters combines a degree of realism with established safety, so that trainees can be allowed to make mistakes and learn from them. Propane gas is used as fuel, with an agent to produce artificial smoke. Pollutants in the exhaust gases have been measured and found to be environmentally acceptable, far superior to training devices these replace. Two companies are using the Navy technology to build trainers for civilian firefighters.

### **2. INTRODUCTION**

Fire fighting on a naval vessel is difficult and hazardous, and can be desperate. The crew cannot leave the action and withdraw. They must win. A naval vessel is usually packed with highly flammable equipment, large amounts of electrical power, fuel, and munitions. Each of these require different fire fighting tactics which require personnel to work as a highly skilled team in the presence of blinding smoke.

Training is essential. It helps to read manuals, but realistic training is needed to ensure that the sailors will do the right thing promptly, and without mistakes. Furthermore, this training of unskilled personnel must be done safely.

It is generally considered that the best training is fighting a real fire, which until recently was the way the U.S. Navy did its training. For instance, to train personnel to fight a fuel fire in the bilge of a ship, the navy built an enclosed concrete building with a bilge-shaped trough in it, floated fuel oil on water in the bilge, and ignited the fuel. Two teams, with two hose streams, would "sweep the fire", diminishing its size until it was extinguished. The reason for two teams and two hose streams was that one stream was needed to keep the forward hose team cool.

Three things are wrong with this realistic approach. First, the training rate in the facility is slow, hence a sailor would be fortunate to have one hot fire experience in a three year enlistment. Secondly for safety, the

instructors were very careful to ensure that the trainees made no mistakes, which is not good teaching practice. It is much better if the trainees can safely make mistakes, be instructed in what they did poorly, and return to try again. The third problem with the realistic approach is that burning fuel oil makes large amounts of smoke and environmentally unacceptable pollutants.

The US Navy is in the later stages of a program to develop and deploy a series of fire fighter trainers using propane gas as a fuel. There will be enough of these trainers to give each seaman one hot training experience per year. Using propane is safer than using liquid fuel because the fire size can be controlled by adjusting the propane flow rate and, in case of emergency a valve can be closed to put the fire out immediately. Also, the compartments can be quickly vented by powerful exhaust fans, if that is needed. In addition, the trainees stand on gratings with makeup air coming up through them, so that they can drop to the grating if they lose their protective clothing or respirators.

To create large yellow-orange flames, the burner designs do not mix air with the fuel gas, but instead let slow jets of the propane burn as turbulent diffusion flames. Since propane burns with little smoke, artificial smoke is added to the compartment for realism. Most smokes would evaporate in the hot gases in the compartment, so smoke is made by vaporizing and recondensing a high boiling, fire-resistant aircraft hydraulic fluid, butylated triphenyl phosphate. Even with these deviations from efficient combustion practice, the generation of pollutants is slight, as will be discussed below.

### 3. DISCUSSION

Figure 1 shows schematically the design of a trainer compartment for simulating a bilge fire in a surface ship, and Figure 2 shows a trainer for bilge and hull insulation fires on a submarine. Figure 3 shows a fire that simulates burning fuel around a crashed aircraft on a carrier deck. This is the only trainer that is not inside a building. The simulated submarine hull insulation fire is shown in Figure 4. In each case the methods of extinguishment, and therefor the training scenarios, are specific to the simulated problem.

#### (A) Operating Conditions

Figure 5 shows typical temperature-time curves for the operation of the training compartment of Figure 1. Figure 6 shows temperature vs. height at a particular time. Note that the temperature well above the trainees heads is 350 °C, which is too hot for safety. This is important because the compartment represents a ship's machinery space, and the trainees approach the fire from a hatch near the top of the compartment. However, with the vent fans turned on, cooler outside air follows the trainees down the stairway leading from the hatch. Also notice that the air a half meter or so above the deck grating, is, as mentioned above, cool, providing a safe haven if a trainee loses his protection.

Figure 7 shows radiant heat flux versus time as measured by two radiometers near the simulated crashed aircraft deck fire of Figure 3. These are with the propane valves fully open. For guidance, consider that a flux of 2.5

watts/cm<sup>2</sup> will quickly ignite crumpled newspaper. Figure 8 is a plot of the radiant flux versus valve opening as measured at right angles to the local wind. It was found that the full size flame, nominally 3.5 meters high, was too hot for the relatively simple turnout gear worn by the trainees, hence the training fire was limited to a height of about 2.5 meters by limiting the fuel valve opening.

The original design, with 3.5 meter high flames, was based on observations of the heights of liquid fuel flames. But the radiation flux from these is greatly reduced by the "tent" of smoke around liquid fuel pool fires. The propane fire does not have this tent of soot, so its thermal radiation for a thick flame of a given height is stronger.

Comprehensive temperature, thermal radiation and gas composition (oxygen, carbon dioxide, and carbon monoxide) measurements were made in each compartment of each kind of trainer. In general there were no problems with the trainers as designed. There are, however, restrictions on the way the trainers can be operated. Naval personnel who have had experience with fighting fires on ships want to turn off the ventilation fans and let the training compartments become very hot and smoky before the trainees enter. Although this adds to realism, it violates safety standards on gas concentration and temperature, so has not been allowed.

## (2) Environmental Aspects:

Typical measured output of pollutants is listed in Table 1.

TABLE 1

<u>SPECIES</u>	<u>% OF THE PROPANE BURNED</u>
Soot	0.22%
Unburned propane	1.2 %
Benzene	0.09%
Toluene	0.005%
Xylenes	0.015%
PAH's	< 2 ppm
Nitrosamines	< 2 ppm
Dioxanes	< 2 ppm

Note: With different burners, these vary by a factor of 2.

Pollutants are measured by drawing the exhaust gas samples from the trainer through "traps", and measuring the species using gas chromatograph-mass spectrometer techniques. At the same time, carbon dioxide is measured in the sample streams, and is used to calculate how much propane was burned to create the species in a given volume of gas sampled.

Soot is collected on a teflon filter and weighed using a microbalance. To obtain enough soot to weigh accurately, typically about 30 minutes of collection are required, at a flow rate of 5 liters/minute. Since the typical trainer run is 5 minutes, the soot is collected during six or so runs.

Benzene, toluene, xylenes, etc. are collected by adsorbing them on Tenax\* adsorbent in a 6.3 mm (1/4 inch) tube. The Tenax adsorbent is first purified by heating it to 250 C for 10 hours or more with ultrapure Helium flowing through it. The usual sample flow rate used is 1 liter/min. This flow rate is too fast to adsorb all the unburned propane, but by reducing the flow rate to 200 cm<sup>3</sup>/min we can get a good calibration curve with standard reference gases containing propane. So unburned propane is measured with a second trap at 200 cm<sup>3</sup>/min.

Polynuclear aromatic hydrocarbons (PAH's) are collected on a teflon filter followed by a commercial adsorbent trap that uses purified Supelco Amberlite XAD-2 resin. Analysis is done according to a method developed by the State of California, adding deuterated PAH's as blanks and then analyzing with the Gas Chromatograph-Mass Spectrometer.

Parenthetically, liquid fuel pool fires create significant quantities of the cancer-causing PAH's. We have never found any in the propane fires, but would have found them if the concentrations were larger than 2 parts per million.

Nitrosamines are collected using a commercial trap and analyzed by the company that makes the trap. Again, detectable amounts of nitrosamines have not been found.

The smoke agent is also relatively benign. Before about 1980, triphenyl phosphate was manufactured by a process that generated about 1% of an impurity, triorthocresyl phosphate, a known neurotoxin. This led to a number of cautions in the literature about keeping it off the skin, washing skin and contaminated clothing, etc. These precautions were not changed when the manufacturing process was changed. As attested by comprehensive toxicological work (1) the new material does not have this problem. It does cause a sore throat or the feeling of a chest cold to some people, but the effect is totally reversible. Trainees do not remain in the smoke long enough to suffer any effects, and instructors wear filter-type masks except when they must speak to the trainees. In practice, there is no toxic effect of the smoke agent.

#### (d) Civilian Trainers:

Civilian firefighters traditionally have carried out hot fire training by burning houses that have been condemned or otherwise scheduled to be removed. The problem with this practice is that a trainee fire fighter occasionally gets hurt or killed if the structure suddenly fails. For reasons similar to the Navy's, the propane-fueled fire fighter trainer technology is attractive to civilian fire fighters. At least two contractors are using the Navy technology to build civilian fighter trainers. They differ from the Navy trainers in that their scenarios are different, for instance a kitchen (cooking) fire, a storage room fire, and a bedroom fire. These trainers are typically too expensive for a single fire company to afford, but purchase may be made by a consortium of fire brigades.

\*Identification of commercial equipment does not imply recommendation by NIST.

#### 4. SUMMARY

The Navy fire fighter trainers use propane gas to create a safe, realistic and environmentally benign training situation, and they will permit a high enough training rate to give each sailor one hot fire experience each year. Some realism is sacrificed to obtain these benefits, but the learning experience is improved over more realistic trainers. Temperatures, radiant heat fluxes, and gas compositions all have been measured. The emission of pollutants is far less than with liquid fuel pool fires.

The Navy's contractors are using the technology developed with Navy trainers to build civilian fire fighter trainers, providing safe, effective, environmentally acceptable training.

#### 5. REFERENCE

(1) Report AAMRL-TR-86-030, "Comparative Studies of the Short Term Toxicity of the Hydraulic Fluids MIL-H-19547C, MIL-H-19547B, and MIL-H-22072B", Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, July 1986.

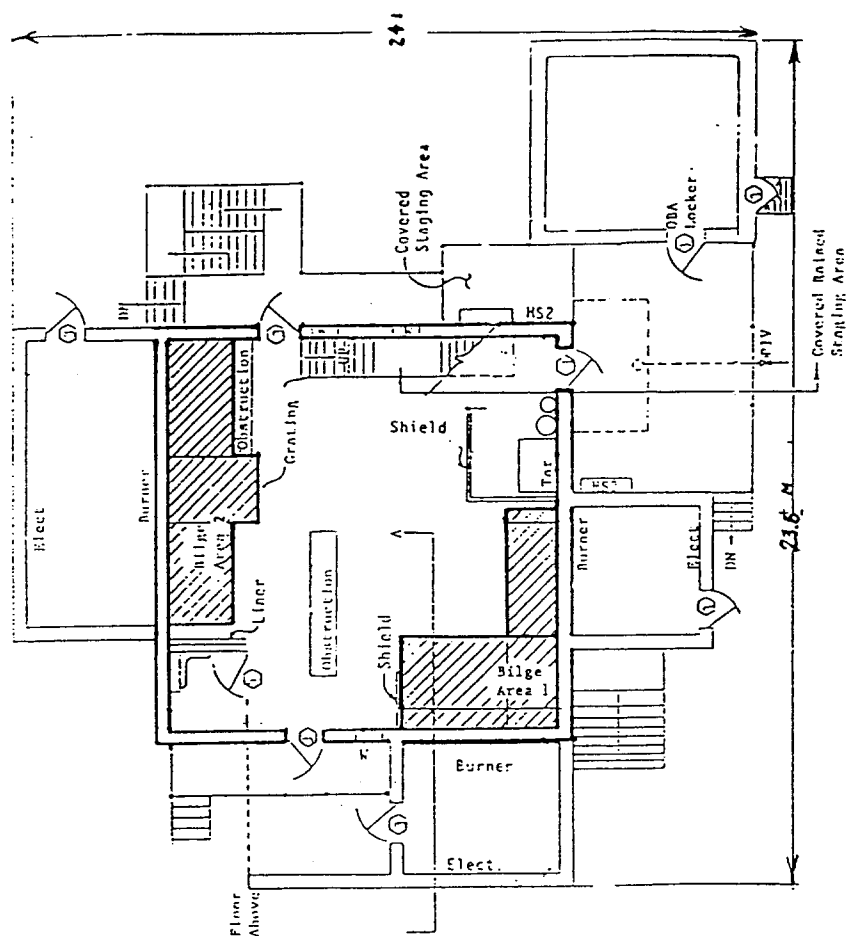


FIGURE 1  
GENERAL SHIPBOARD FIRE FIGHTING TRAINER  
BILGE FIRE SIMULATION COMPARTMENT

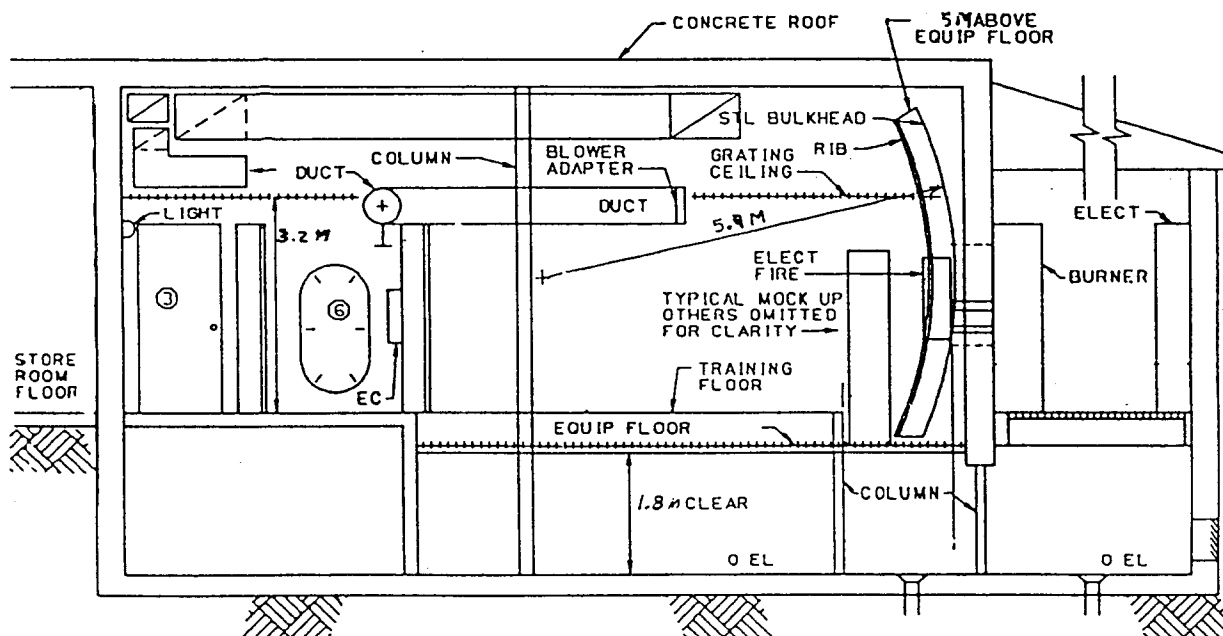


FIGURE 2  
SUBMARINE FIRE FIGHTING TRAINER  
SIDE VIEW

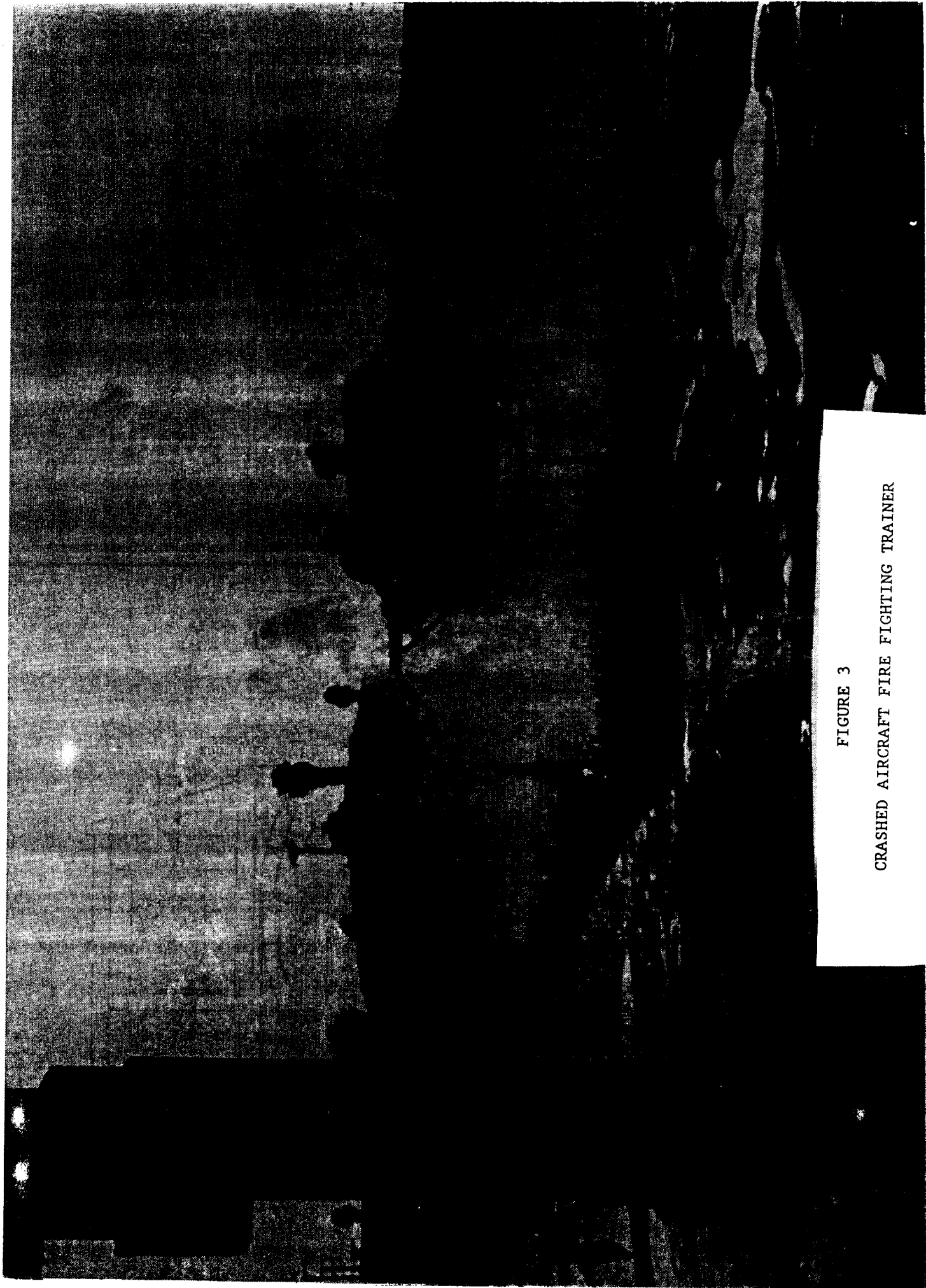


FIGURE 3  
CRASHED AIRCRAFT FIRE FIGHTING TRAINER



FIGURE 4

HULL INSULATION FIRE

SUBMARINE FIRE FIGHTING TRAINER

